CHAPTER 7

A SURVEY OF "RANDOM" WAVE GENERATION TECHNIQUES

by J. Ploeg* and E.R. Funke**

Techniques of producing waves in hydraulic models and laboratory flumes have evolved from the simple electrical-mechanical technique of some 15 years ago, to the present sophisticated hydraulic-electric servo systems, controlled by on-line computers and capable of producing a large number of different types of sea states. An accurate definition of the required sea state has become very important, since it has been shown that different types of wave trains, although all having the same significant wave heights and periods, can produce large differences in the results of model tests. Even a specification of the input spectrum, including all relevant spectral parameters, is not sufficient. The occurrance of wave groups, for instance, has to be defined separately. Table 1 illustrates which sea state parameters (A-E) need to be defined and controlled in the laboratory for different types of model studies (1-9). This is just shown as an example, and does not pretend to be a definitive statement.

There exists presently a great variety of different techniques and methods to produce irregular waves and there is no assurance that testing the same model in different laboratories will give similar results. As a first step to address this problem, it was thought to be useful to determine the variety (or perhaps similarity) of all laboratory wave generation systems presently used. A discussion with representatives of a number of hydraulics laboratories and ship towing tanks in the spring of 1979 led to the organisation of a survey of wave generation and analysis systems. The results of the survey are shown in the same format as the questionnaire. A list of all institutes which participated is also included.

Summarizing the results of the survey is impossible within the text of this paper. A general conclusion to be drawn is, that there is a surprisingly large uniformity in the equipment and facilities used for modelling waves. Also, for the suggested definition of sea state, it would not be difficult to list the generally accepted parameters:

$$(S_I(f),\ S_R(f),\ f_p,\ H_{m_o},\ \varepsilon_s,\ Q_p \text{ and } H_{z,max},\ T_{H_{z,max}},\ H_{1/3},\ \overline{T}_z)$$

Many laboratories mention wave grouping, but only three institutes suggest a definition of the grouping parameter.

It appears that the next logical step has to be a draft proposal of a standard set of methods of wave generation techniques and data analysis methods, based on the results of this survey. The discussion of this presentation at the conference seemed to suggest to involve an existing international organisation, such as the IAHR, to produce such a draft. Other laboratories will hopefully perceive the need for an agreement on standard wave generation techniques and analysis methods, and actively cooperate with this project.

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SEA STATE PARAMETERS IN COASTAL AND MARINE ENGINEERING STUDIES

TYPES OF STUDIES	SEA STATE PARAMETERS				
	A	B	C	D	E
1. STABILITY OF RUBBLE MOUND BREAKWATERS	X	X	X	X	X
2. FORCES AND PRESSURES ON OFFSHORE STRUCTURES	X	X	X	X	X
3. HARBOUR RESPONSE	X	X		X	
4. STABILITY OF FLOATING STRUCTURES	X		X	X	X
5. RESPONSE OF FLOATING STRUCTURES	X	X		X	X
6. STRESSES IN SHIP HULLS	X	X	X	X	X
7. MOORING FORCES FOR MOORED VESSELS	X	X	X	X	X
8. BEACH PROCESSES	X	X		X	
9. WAVE ENERGY EXTRACTION	X	X	X	X	X

A. TOTAL SPECTRUM, $S(f)$; PEAK FREQUENCY, f_p;
PEAK PERIOD, $T_p = 1/f_p$; RMS = $\sqrt{m_0}$; BROADNESS FACTOR

B. INCIDENT AND REFLECTED SPECTRA, $S_I(f)$ AND $S_R(f)$;
COEFFICIENT OF REFLECTION $C_R(f)$

C. WAVE HEIGHT DISTRIBUTION PARAMETERS, H_s, H_{MAX};
PERIODS, T_{H_s}, $T_{H_{MAX}}$

D. SIWEH, $E(t)$; AVERAGE WAVE ENERGY, $\bar{E}$;
SIWEH SPECTRAL DENSITY, $\epsilon(f)$; PEAK FREQUENCY OF ϵ, $f_{p\epsilon}$;
GROUPINESS FACTOR, GF

E. WAVE SLOPE DISTRIBUTION, $D(S)$;
MAXIMUM WAVE SLOPE, S_{MAX}

TABLE 1

DATA REPORT OF QUESTIONNAIRES ON
WAVE GENERATION AND ANALYSIS SYSTEMS

GENERAL

Total number of questionnaires sent out to Hydraulics Lab:	184	
Total number of replies received from Hydraulics Labs:	98	(53%)
Total number of questionnaires sent out to Ship Towing Tanks:	74	
Total number of replies received from Ship Towing Tanks:	44	(59%)
Number of institutes included in replies which reported not having wave making facilities: Hydraulics Labs:	15	
Ship Towing Tanks:	9	

The 83 Hydraulics Labs with wave making facilities reported a total of:

176 flumes equipped for regular waves
79 flumes equipped for irregular waves
15 flumes equipped for transient waves

112 basins equipped for regular waves
39 basins equipped for irregular waves
7 basins equipped for transient waves.

The 35 Towing Tanks with wave making facilities reported a total of:

51 flumes equipped for regular waves
31 flumes equipped for irregular waves
13 flumes equipped for transient waves

22 basins equipped for regular waves
18 basins equipped for irregular waves
6 basins equipped for transient waves.

A. TANKS AND WAVE MACHINES

Note: A distinction was made between wave flumes and wave basins in analyzing the questionnaires. When the length of a tank is larger than 5X the width it was classified as a "Flume"; when the length of a tank is smaller than 5X the width, it was classified as a "Basin". Also, the ranges of tank dimension were set at different limits for Hydraulics Laboratories and Ship Towing Tanks.

HYDRAULICS LABORATORIES

Flumes:

Width		Length		Depth	
Range (m)	Number	Range (m)	Number	Range (m)	Number
≤0.99	85	≤24.9	47	≤0.49	18
1.0-2.99	58	25.0-49.9	79	0.5-0.99	78
3.0-4.99	29	50.0-99.9	40	1.0-1.99	75
≥5.0	13	≥100.0	21	≥2.0	16

Type of Wave Machines in Flumes (see Fig. 1):

Types	A	B	C	D	E	F	G	H	K	L	M	N	O	P	Q	R	S	T
Number	33	61	5	4	6	0	28	1	3	5	13	7	4	0	7	4	3	2

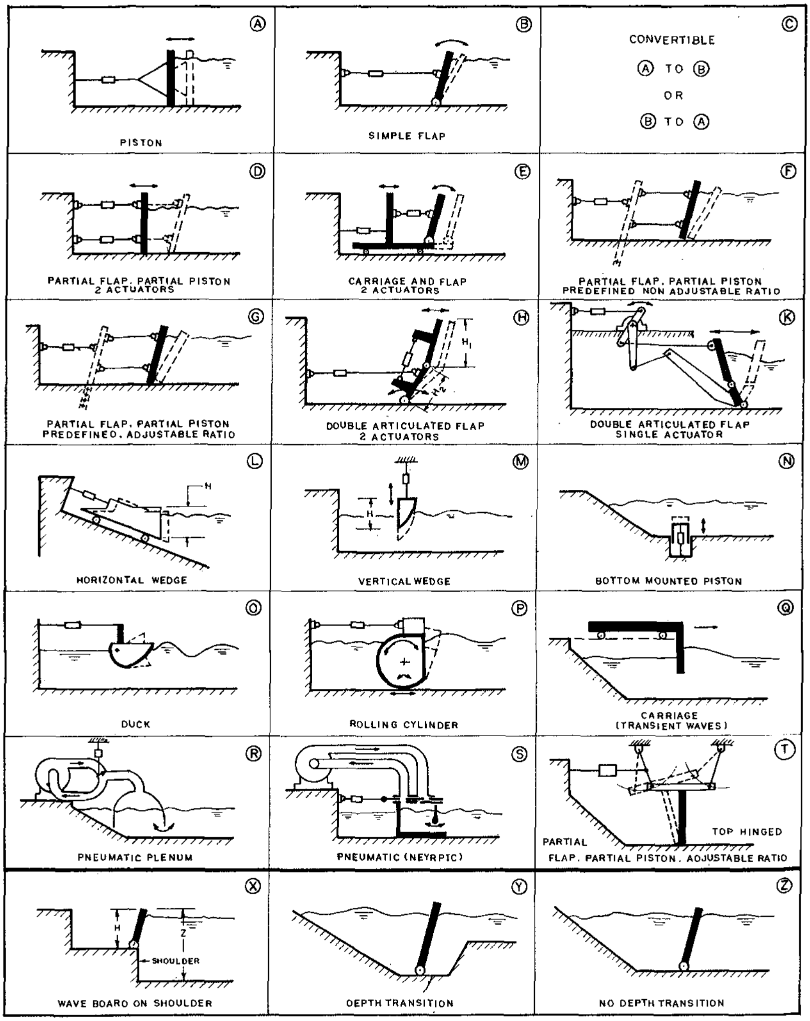

FIG.1

NATIONAL RESEARCH COUNCIL
HYDRAULICS LABORATORY
OTTAWA, CANADA
JULY 17, 1979

Other Features of Wave Machines in Flumes:

	Fixed	Movable	X	Y	Z	Air	Water
Number	165	20	6	48	128	18	162

Drive	Electric Motor & Gears	Electronic/Electric Servo	Hydraulic/Electric Servo
Number	109	20	57

Features of Flumes:

	Recirculation in tank		Short-Crested Wave Capability		Wind Capability	
	Yes	No	Yes	No	Yes	No
Number	69	118	26	154	50	136

Basins:

Length + Width		Depth	
Range (m)	Number	Range (m)	Number
≤29.9	27	≤0.49	33
30.0-49.9	34	0.5 - 0.74	36
50.0-99.9	50	0.75-0.99	29
≥100.0	8	≥1.0	22

Type of Wave Machines in Basins: (see Fig. 1)

Types	A	B	C	D	E	F	G	H	K	L	M	N	O	P	Q	R	S	T
Number	34	44	4	2	0	1	8	0	3	2	9	4	1	0	2	2	1	3

Other Features of Wave Machines in Basins:

	Fixed	Movable	X	Y	Z	Air	Water
Number	51	71	10	28	83	1	115

Drive	Electric Motor & Gears	Electronic/Electric Servo	Hydraulic/Electric Servo
Number	77	10	35

Features of Basins:

	Recirculation in tank		Short-Crested Wave Capability		Wind Capability	
	Yes	No	Yes	No	Yes	No
Number	46	73	33	85	11	108

SHIP TOWING TANKS:

Flumes:

Width		Length		Depth	
Range (m)	Number	Range (m)	Number	Range (m)	Number
≤4.9	15	≤99.9	20	≤2.9	21
5.0-9.9	21	100.0-199.9	18	3.0-4.9	18
10.0-14.9	13	200.0-299.9	13	5.0-6.9	12
≥15.0	6	≥300.0	4	≥7.0	4

Type of Wave Machines in Flumes: (see Fig. 1)

Types	A	B	C	D	E	F	G	H	K	L	M	N	O	P	Q	R	S	T
Number	1	21	0	2	0	0	2	5	0	0	16	0	0	0	0	7	1	0

Other Features of Wave Machines in Flumes:

	Fixed	Movable	X	Y	Z	Air	Water
Number	48	8	18	1	28	7	39

Drive	Electric Motor	Electronic/Electric Servo	Hydraulic/Electric Servo
Number	23	6	27

Features of Flumes:

	Recirculation in tank		Short-Crested Wave Capability		Wind Capability	
	Yes	No	Yes	No	Yes	No
Number	11	43	7	47	14	40

Basins:

Length + Width		Depth	
Range (m)	Number	Range (m)	Number
≤99.0	12	≤0.99	3
100.0-199.9	10	1.0-1.99	4
200.0-299.9	1	2.0-2.99	6
≥300.0	0	≥3.0	10

Type of Wave Machines in Basins: (see Fig. 1)

Types	A	B	C	D	E	F	G	H	K	L	M	N	O	P	Q	R	S	T
Number	2	10	0	1	0	0	2	1	0	0	5	0	0	0	0	5	0	0

Other Features of Wave Machines in Basins:

	Fixed	Movable	X	Y	Z	Air	Water
Number	19	6	6	1	17	4	16

Drive	Electric Motor & Gears	Electronic/Electric Servo	Hydraulic/Electric Servo
Number	13	3	9

Features of Basins:

	Recirculation in tank		Short-Crested Wave Capability		Wind Capability	
	Yes	No	Yes	No	Yes	No
Number	4	19	5	20	4	19

Hydraulics Laboratories

B. IRREGULAR WAVE GENERATION SYSTEMS

B.1 The following information describes which method of irregular wave generation you employ. Please check one or more of the following systems, adding a W if wind is added to the basic method. Please indicate present practice and/or anticipated practice in future, where applicable. *(78 Laboratories responded in some way.)*

			Now	Future
(a)	Harmonic Synthesis:	(i) by mechanical gear system	*15*	*4*
		(ii) by special purpose electronic device	*8*	*6*
		(iii) by computer (other than Fourier transform)	*8*	*12*
(b)	True Random White Noise (e.g. Thermal or Cosmic) and analog shaping filters		*8*	*7*
(c)	Pseudo Random Noise:	(i) by on-line computer	*7*	*14*
		(ii) by special purpose electronic device	*12*	*10*
(d)	Reproduction of Prototype Wave Train:			
		(i) by punched paper tape	*10*	*7*
		(ii) by analog magnetic tape	*15*	*9*
		(iii) by digital magnetic tape	*4*	*5*
		(iv) by on-line computer	*9*	*22*
(e)	Synthesis by Fourier Transform Technique:			
		(i) by on-line computer	*8*	*18*
		(ii) by off-line computer	*18*	*15*
(f)	Frequency Sweep by varying the speed of the actuator drive motor		*7*	*5*
(g)	Wind Alone		*12*	*5*
(h)	Other (please specify)			

B.2 The following information defines some of the details of the systems described in B.1. Please check or give details where applicable.

(a) For harmonic synthesis, give number of discrete frequencies which participate. *Varies from 2 to 1024; node at (20)*

(b) Are these frequencies integer multiples of a fundamental component? (+ or -) *14-; 5+*

(c) Give range of repetition periods of the irregular wave train
(i) minimum *(40)* sec; *0.5 - 3600*
(ii) typical *(300)* sec; *5 - 10800*
(iii) maximum *(1000)* sec; *2 - ∞*

(d) Is the test period an integer multiple of the repetition period

(i) always *7* (ii) sometimes *19* (iii) never *7*

Hydraulics Laboratories

(e) Do you use compensation techniques for

(i) the wave board dynamic transfer function (+ or -)	*28+; 12-*
(ii) the servo dynamic transfer function (+ or -)	*22+; 17-*
(iii) the analog low-pass filter (+ or -)	*16+; 20-*

(f) If you use time discrete driving signals (i.e. involving digital to analog converters), what is the typical time step rate? *0.01 - 0.2; node at (0.1)* sec

(g) For (f) above, what smoothing do you use?

(i) analog low-pass filter	*20 now;*	*14 future*
(ii) straight line interpolator	*4 now;*	*3 future*
(iii) none	*11 now;*	*2 future*

(h) Do you attempt to control wave steepness by phase control?

(i) always	*1 now;*	*1 future*
(ii) sometimes	*7 now;*	*12 future*
(iii) never	*29 now;*	*5 future*

C. DATA ACQUISITION SYSTEM

The following information describes your data acquisition system. Please check or give details where applicable. Please check to indicate present practice and/or anticipated practice in future, where applicable.

	Never		Sometimes		Every Test	
	Now	Future	Now	Future	Now	Future
(a) What methods of data recording do you employ?						
(i) Strip-chart recorder	*5*	*1*	*30*	*25*	*26*	*13*
(ii) Analog magnetic tape recorder	*6*	*5*	*30*	*22*	*3*	*5*
(iii) Digital data logger for off-line analysis	*12*	*8*	*10*	*14*	*4*	*8*
(iv) On-line digital computer (please give computer model no.) *10 H.P.; 9 PDP*	*7*	*2*	*24*	*21*	*9*	*13*

(b) How many wave probes do you employ for:

(i) Harbour studies?	*Varies from 1-120;*	*node (12)*
(ii) Breakwater studies?	*Varies from 1-20;*	*node (3)*
(iii) Beach process studies?	*Varies from 1-20;*	*node (6)*
(iv) Offshore fixed structures?	*Varies from 1-20;*	*node (5)*
(v) Floating structure studies?	*Varies from 2-20;*	*node (5)*
(vi) Others?		

D. DATA ANALYSIS SYSTEM

The following information defines details of the analysis system you use for simulated sea states, as measured in your laboratory tanks. Please indicate present practice and/or anticipated practice in future, where applicable. All notations follow the PIANC report of the International Commission for the Study of Waves.

	Never		Sometimes		Every Test	
	Now	Future	Now	Future	Now	Future
(a) How frequently do you perform wave analysis?	*3*	*0*	*23*	*14*	*34*	*29*

Hydraulics Laboratories

		Never		Sometimes		Every Test	
		Now	Future	Now	Future	Now	Future
(b)	Do you carry out the analysis by the following techniques						
	(i) Visual inspection of graphic records?	5	6	27	19	18	7
	(ii) Off-line computer?	8	5	25	20	15	10
	(iii) On-line computer?	4	1	20	22	10	16
(c)	Which time domain analysis do you normally perform:						
	(i) Zero-up crossing?	4	2	21	18	21	19
	(ii) Zero-down crossing?	8	6	11	10	5	3
	(iii) Other (please specify)						
(d)	Which time domain parameters do you derive?						
	(i) $H_{z,1/3}$	4	2	26	15	24	28
	(ii) $H_{z,max}$	5	2	28	18	18	20
	(iii) $\overline{T}_z$	7	3	22	15	23	21
	(iv) $T_{H_{z,1/3}}$	10	3	14	12	14	14
	(v) $T_{H_{z,max}}$	8	3	18	16	9	9
	(vi) $\varepsilon_T^2 = 1 - (\overline{T}_c/\overline{T}_z)^2$	18	10	9	10	5	8
	(vii) Others (please specify)						
(e)	Which frequency domain functions and parameters do you derive:						
	(i) Fourier transform (periodogram)	9	2	24	22	4	6
	(ii) Power spectral density	2	0	27	19	21	18
	(iii) F_p (peak frequency)	5	0	22	19	18	17
	(iv) T_p (= $1/F_p$)	5	0	23	18	16	17
	(v) $\sigma = \sqrt{\int S(f) \cdot df}$	5	0	19	14	21	18
	(vi) $H_{m_0} = 4*\sigma$	7	0	14	15	16	17
	(vii) $T_{m_{01}} = m_0/m_1$	11	5	18	14	7	7
	(viii) $T_{m_{02}} = \sqrt{m_0/m_2}$	12	4	21	17	5	6
	(ix) $\varepsilon_s = \sqrt{1 - m_2^2/m_0\, m_4}$	12	5	18	18	7	8
	(x) Others (please specify) $Q_p = 2/m_0^{\,2} \int_0^\infty f S^2(f)\, df$						

		Never		Sometimes		Every Test	
		Now	Future	Now	Future	Now	Future
(f)	Do you describe groupiness? (please specify)	29	2	15	22	0	4
(g)	Do you describe particular wave sequences? (please specify)	26	2	17	26	0	3
(h)	Do you derive wave steepness by						
	(i) Calculation?	16	0	24	26	6	4
	(ii) Measurement?	17	2	18	25	3	3

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	Never Now	Never Future	Sometimes Now	Sometimes Future	Every Test Now	Every Test Future
(j) Do you measure structural or beach reflections in the presence of irregular waves?	*21*	*1*	*24*	*30*	*4*	*9*

E. Please comment below on how to define the essential parameters of a sea state.

Ship Towing Tanks

B. IRREGULAR WAVE GENERATION SYSTEMS

B.1 The following information describes which method of irregular wave generation you employ. Please check one or more of the following systems, adding a W if wind is added to the basic method. Please indicate present practice and/or anticipated practice in future, where applicable. *(32 Institutes responded in some way.)*

		Now	Future
(a) Harmonic Synthesis:	(i) by mechanical gear system	*3*	*1*
	(ii) by special purpose electronic device	*11*	*4*
	(iii) by computer (other than Fourier transform)	*7*	*11*
(b) True Random White Noise (e.g. Thermal or Cosmic) and analog shaping filters		*4*	*1*
(c) Pseudo Random Noise:	(i) by on-line computer	*3*	*13*
	(ii) by special purpose electronic device	*7*	*7*
(d) Reproduction of Prototype Wave Train:			
	(i) by punched paper tape	*3*	*0*
	(ii) by analog magnetic tape	*16*	*6*
	(iii) by digital magnetic tape	*2*	*2*
	(iv) by on-line computer	*1*	*14*
(e) Synthesis by Fourier Transform Technique:	(i) by on-line computer	*3*	*10*
	(ii) by off-line computer	*13*	*4*
(f) Frequency Sweep by varying the speed of the actuator drive motor		*8*	*4*
(g) Wind Alone		*2*	*2*
(h) Other (please specify)			

Ship Towing Tanks

B.2 The following information defines some of the details of the systems described in B.1. Please check or give details where applicable.

(a) For harmonic synthesis, give number of discrete frequencies which participate *Varies from 6 to 256; node at (20)*

(b) Are these frequencies integer multiples of a fundamental component? (+ or -) *6+; 14-*

(c) Give range of repetition periods of the irregular wave train
(i) minimum *(40)* sec; *2 - 300*
(ii) typical *(300)* sec; *20 - ∞*
(iii) maximum sec; *90 - ∞*

(d) Is the test period an integer multiple of the repetition period
(i) always *4* (ii) sometimes *11* (iii) never *8*

(e) Do you use compensation techniques for
(i) the wave board dynamic transfer function (+ or -) *17+; 5-*
(ii) the servo dynamic transfer function (+ or -) *16+; 7-*
(iii) the analog low-pass filter (+ or -) *10+; 6-*

(f) If you use time discrete driving signals (i.e. involving digital to analog converters), what is the typical step rate? *0.39-1.0; node at (0.1) sec*

(g) For (f) above, what smoothing do you use?
(i) analog low-pass filter *7 now; 5 future*
(ii) straight line interpolator *2 now; 2 future*
(iii) none *3 now; 0 future*

(h) Do you attempt to control wave steepness by phase control?
(i) always *0 now; 1 future*
(ii) sometimes *6 now; 10 future*
(iii) never *14 now; 0 future*

C. DATA ACQUISITION SYSTEM

The following information describes your data acquisition system. Please check or give details where applicable. Please indicate present practice and/or anticipated practice in future, where applicable.

	Never Now	Never Future	Sometimes Now	Sometimes Future	Every Test Now	Every Test Future
(a) What methods of data recording do you employ?						
(i) Strip-chart recorder	*1*	*1*	*10*	*12*	*14*	*5*
(ii) Analog magnetic tape recorder	*2*	*1*	*15*	*12*	*10*	*4*
(iii) Digital data logger for off-line analysis	*7*	*4*	*4*	*8*	*4*	*2*
(iv) On-line digital computer (please give computer model no.)	*6*	*3*	*7*	*9*	*10*	*12*

	Ship Towing Tanks
(b) How many wave probes do you employ for:	
(i) Ship motion studies?	*Varies from 1-10; node at (2)*
(ii) Floating structures studies?	*Varies from 1-6; node at (2)*
(iii) Fixed structure studies?	*Varies from 1-10; node at (2)*
(iv) Others?	

D. DATA ANALYSIS SYSTEM

The following information defines details of the analysis system you use for simulated sea states, as measured in your laboratory tanks. Please indicate present practice and/or anticipated practice in future, where applicable. All notations follow the PIANC report of the International Commission for the Study of Waves.

	Never		Sometimes		Every Test	
	Now	Future	Now	Future	Now	Future
(a) How frequently do you perform wave analysis?	*0*	*0*	*5*	*2*	*24*	*20*
(b) Do you carry out the analysis by the following techniques						
(i) Visual inspection of graphic records?	*0*	*0*	*11*	*7*	*12*	*8*
(ii) Off-line computer?	*1*	*1*	*11*	*10*	*12*	*6*
(iii) On-line computer?	*2*	*0*	*4*	*5*	*11*	*16*
(c) Which time domain analysis do you normally perform:						
(i) Zero-up crossing?	*3*	*1*	*9*	*11*	*8*	*2*
(ii) Zero-down crossing?	*4*	*1*	*5*	*4*	*1*	*1*
(iii) Other (please specify)						
(d) Which time domain parameters do you derive?						
(i) $H_{z,1/3}$	*1*	*0*	*9*	*11*	*15*	*7*
(ii) $H_{z,max}$	*1*	*0*	*11*	*10*	*11*	*4*
(iii) $\overline{T}_z$	*2*	*0*	*11*	*4*	*8*	*3*
(iv) $T_{H_{z,1/3}}$	*5*	*2*	*4*	*7*	*4*	*2*
(v) $T_{H_{z,max}}$	*3*	*1*	*7*	*8*	*2*	*1*
(vi) $\varepsilon_T^2 = 1 - (\overline{T}_c/\overline{T}_z)^2$	*5*	*1*	*6*	*8*	*5*	*1*
(vii) Others (please specify)						
(e) Which frequency domain functions and parameters do you derive:						
(i) Fourier transform (periodogram)	*3*	*1*	*12*	*11*	*5*	*4*
(ii) Power spectral density	*0*	*0*	*8*	*5*	*21*	*14*
(iii) F_p (peak frequency)	*2*	*0*	*6*	*6*	*13*	*8*
(iv) T_p (= $1/F_p$)	*2*	*0*	*6*	*5*	*14*	*8*

	Ship Towing Tanks					
	Never		Sometimes		Every Test	
	Now	Future	Now	Future	Now	Future
(v) $\sigma = \sqrt{\int S(f) \cdot df}$	0	0	8	4	18	12
(vi) $H_m = 4 * \sigma$	1	0	6	4	17	13
(vii) $T_{m_{01}} = m_0/m_1$	2	0	13	8	7	6
(viii) $T_{m_{02}} = \sqrt{m_0/m_2}$	2	0	16	9	6	4
(ix) $\varepsilon_s = \sqrt{1 - m_2^2/m_0 \cdot m_4}$	2	0	12	8	9	6
(x) Others (please specify)						
(f) Do you describe groupiness? (please specify)	21	1	1	13	0	4
(g) Do you describe particular wave sequences? (please specify)	14	1	5	13	0	1
(h) Do you derive wave steepness by						
(i) Calculation?	6	0	13	12	4	2
(ii) Measurement?	9	1	8	9	0	1
(j) Do you measure structural or beach reflections in the presence of irregular waves?	19	5	6	9	0	0

E. Please comment below on how to define the essential parameters of a sea state.

LIST OF INSTITUTES WHICH PARTICIPATED IN
THE SURVEY OF WAVE GENERATION AND ANALYSIS SYSTEMS

Hydraulics Laboratories

Monash University
Victoria, Australia

University of Adelaide
Adelaide, Australia

State Rivers and Water Supply
Commission
Victoria, Australia

University of New South Wales
Manly Vale, Australia

Department of Public Works N.S.W.
Manly Vale, Australia

Snowy Mountains Engineering Corp.
Cooma, Australia

University of Tasmania
Tasmania, Australia

University of Melbourne
Parkville, Victoria, Australia

University of Western Australia
Nedlands, W. Australia

Universiteit te Gent
Gent, Belgium

University of Liege
Liege, Belgium

COPPE/UFRJ - PENO
Rio de Janeiro, Brasil

HIDROESB - Saturnino de Brito
Hydraulic Laboratory
Rio de Janeiro, Brasil

National Institute for
Waterways Research
Rio de Janeiro, Brasil

Queens University
Kingston, Canada

Ecole Polytechnique
Montreal, Canada

National Research Council of Canada
Ottawa, Canada

National Water Research Institute
Burlington, Canada

Université Laval
Ste. Foy, Canada

Arctec Canada Ltd.
Kanata, Canada

University of Saskatchewan
Saskatoon, Canada

Ontario Hydro
Toronto, Canada

Universität Hamburg
Hamburg, West Germany

Technical University of Berlin
Berlin, Germany

Technischen Universität Braunschweig
Braunschweig, Germany

Technical University of Hannover
Hannover, Germany

Technical University München
München, Germany

Universität Stuttgart
Stuttgart, Germany

Aalborg Universitetscenter
Aalborg, Denmark

Danish Hydraulic Institute
Horsholm, Denmark

Technical University of Denmark
Lyngby, Denmark

Suez Canal Research Centre
Ismailia, Arab Republic of Egypt

Laboratoire National d'Hydraulique
Chatou, France

British Hovercraft
Isle of Wight, U.K.

University of Bristol
Bristol, England

Wimpey Laboratories Ltd.
London, Great Britain

British Transport Docks Board
Middlesex, England

Hydraulics Research Station
Wallingford, England

British Hydromechanic Research Association
Cranfield, England

Research Centre for Water Resources Development
Budapest, Hungary

Hydraulic and Hydraulic Structures Institute
Genova, Italia

Politecnico di Torino
Torino, Italia

Coastal and Marine Engineering Research Institute
Haifa, Israel

Indian Institute of Technology, Bombay
Bombay, India

Maharashtra Engineering Research Institute
Maharashtra State, India

Central Water and Power Research Station
Poona, India

Irrigation Research Station
Tamil Nadu, India

Karnataka Engineering Research Station
Krishnarajsagara
Karnatka State, India

Karnataka Regional Engineering College
Surathkal
Karnataka State, India

Motilal Nehru Regional Engineering College
Allahabad, India

Land Reclamation, Irrigation and Power Research Institute
Punjab, Amritsar, India

Jawaharlalnearu Technological University
Pradesh, India

Maulana Azad College of Technology
Bhopal, India

Indian Institute of Technology, Kanpur
Kanpur, India

Indian Institute of Technology
Madras India

U.P. Irrigation Research Institute
Roorkee, India

Regional Engineering College
Kashmir, India

Port and Harbour Research Institute
Ministry of Transport
Yokosuka, Japan

First District Port Construction Bureau
Ministry of Transport
Niigata, Japan

Central Research Institute of Electric Power Industry
Abiko City, Japan

Kyoto University
Kyoto, Japan

Disaster Prevention Research Institute
Kyoto, Japan

Osaka City University
Osaka, Japan

Tohoku University
Sendai, Japan

University of Tokyo
Tokyo, Japan

Public Works Research Institute
Ibaraki-Ken, Japan

River and Harbour Laboratory
Trondheim, Norway

Delft University of Technology
Delft, The Netherlands

Delft Hydraulics Laboratory
Delft, The Netherlands

Ministry of Works and Development
Lower Hutt, New Zealand

National Laboratory of Civil Engineering
Lisbon, Portugal

Institute of Hydroengineering
Polisy Academy of Sciences
Gdańsk, Poland

Hydraulic Engineering Research Institute
Bucuresti, Romania

Hydraulics Laboratory
"Cuillermo C.Cēspedes"
La Plata, Argentina

Institute of Hydraulic Engineering
Ministry of Public Works
Bandung, Indonesia

Chalmers University of Technology
Cōteborg, Sweden

Dept. of Water Resources Engineering
Lunds Universitet
Lund, Sweden

Royal Institute of Technology
Stockholm, Sweden

IVO Hydraulic Laboratory
Helsinki, Finland

Asian Institute of Technology
Bangkok, Thailand

Middle East Technical University
Ankara, Turkey

University of California
Berkeley, U.S.A.

U.S. Army Engineer Waterways Experiment Station
Vicksburg, U.S.A.

Civil Engineering Laboratory
Naval Construction Battalion Centre
Port Hueneme, U.S.A.

University of Florida
Cainesville, U.S.A.

University of Iowa
Iowa, U.S.A.

University of Illinois
Urbana, U.S.A.

Massachusetts Institute of Technology
Cambridge, U.S.A.

U.S. Dept. of the Interior
Bureau of Reclamation
Denver, U.S.A.

Water Conservation Structures Laboratory
U.S. Department of Agriculture
Stillwater, U.S.A.

Hydraulics Laboratory
Ann Arbor, U.S.A.

Saint Anthony Falls Hydraulic Laboratory
Minneapolis, U.S.A.

Webb Institute of Naval Architecture
Clen Cove, U.S.A.

Oregon State University
Corvallis, U.S.A.

University of Texas
Austin, U.S.A.

Texas A and M University
Texas, U.S.A.

University of Washington
Seattle, U.S.A.

Coastal Engineering Research Center
Fort Belvoir, U.S.A.

Chicago Bridge and Iron Co.
Illinois, U.S.A.

University of Witwatersrand
Johannesburg, South Africa

National Research Institute for Oceanology
Stellenbosch, South Africa

University of Stellenbosch
Stellenbosch, South Africa

Ship Towing Tanks

Bulgarian Ship Hydrodynamics Centre
Varna, Bulgaria

Shanghai Chiao-Tung University
Shangai, China

Shanghai Ship Design and Research Institute
Shanghai, China

China Ship Scientific Research Centre
Kiangsu Province, China

Helsinki University of Technology
Expoo, Finland

Wartsila Icebreaking Model Basin
Helsinki, Finland

Hiroshima University
Hiroshima, Japan

Korea Research Institute of Ship
Daejeon, Korea

National Research Council
Ottawa, Canada

Ship Research Laboratory
Lyngby, Denmark

Versuchsanst für Binnenschiffbau
Duisburg, Cermany

Hamburg Shipmodel Basin (HSVA)
Hamburg, Germany

Versuchsanstalt für Wasserbau und Schiffbau
Berlin, Cermany

Bassin d'Essais des Carenes
Paris, France

Institut de Recherches de la Construction Navale
Paris, France

Indian Institute of Technology
Kharagpur, India

Universita deliga Studi di Napoli
Napoli, Italy

Universita di Cenova
Cenova, Italy

Technical Research and Development Institute
Japan Defence Agency
Tokyo, Japan

University of Tokyo
Tokyo, Japan

University of Osaka
Osaka, Japan

Heavy Industries Ltd.
Yokohama, Japan

Mitsubishi Heavy Industries Ltd.
Nagasaki, Japan

Akashi Ship Model Basin Co., Ltd.
Akashi City, Japan

Shipbuilding Research Centre of Japan
Tokyo, Japan

Seoul National University
Seoul, Korea

Technological University
Delft, The Netherlands

Norwegian Hydrodynamic Laboratories
Trondheim, Norway

Ship Design and Research Centre
Gdanski, Poland

Ministerio de Defensa Marina
Madrid, Spain

Statens Skeppsprovningsanstalt
Goteborg, Sweden

University of Newcastle
Newcastle-upon-Tyne, U.K.

British Ship Research Association
Wallsend, United Kingdom

Admiralty Marine Technology Establishment
Gosport, United Kingdom

National Maritime Institute of Technology
Cambridge, U.S.A.

Offshore Technology Corporation
Escondido, U.S.A.

Stevens Institute of Technology
Hoboken, U.S.A.

United States Naval Academy
Annapolis, U.S.A.

University of Michigan
Ann Arbor, U.S.A.

David Taylor Naval Ship Research and Development Center
Bethesda, U.S.A.

Pennsylvania State University
Pennsylvania, U.S.A.

Hydronautics, Incorporated
Laurel, Maryland, U.S.A.